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Modeling the Change of Mangrove Forests in Irrawaddy Delta, South Myanmar

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Abstract

Mangrove forests distributed along the coastal areas and river deltas in tropical and subtropical regions provide fundamental ecological services and habitats for a variety of wildlife species. Because of the conversion of mangrove forests to agricultural lands, the dramatic decline of mangrove forests in Irrawaddy Delta, South Myanmar during the past 30 years has been noticed and caused environment impacts, including habitat loss, reduction of biodiversity, and the increase of coastal erosion. This study firstly aims to investigate the changes of mangrove forests over the region of Irrawaddy Delta, using Landsat imageries during the periods of 1989 to 2014. Second, a land cover modeling tool, Probabilistic Landscape Simulation (ProLAMS), is developed and applied for modeling and predicting the change of mangrove forests. Specifically, ProLAMS adopts logistic regression analysis and cellular automata to assess the likelihood of future mangrove forest distribution. Two major findings are: (1) from 1989 to 2014, about 26.7% decline of mangrove forest has been detected; (2) ProLAMS predicts 16.8% decline of mangrove area from 2014 to 2030. In sum, this study suggests that satellite imagery and the proposed model can provide the prediction of future scenarios for mangrove forests. We expect this approach can be useful and applicable for other regions to assist ecosystem conservation activity.

Keywords: Mangrove forest; Landsat imagery; change detection; ProLAMS; Irrawaddy Delta.

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1. Introduction

Mangrove forests typically fringe the transition zone between land and sea in intertidal coastal regions, estuary, and reef environments, which are characterized by strong winds, varying inundation, high temperatures, and anaerobic muddy soil. Mangrove forests cover up to 75.0% of the tropical and subtropical shorelines [1] and growing within equatorial regions achieve their maximum biomass. It is estimated that the total area of mangroves is about 152,000 km^2 [2]. There is much debate over the statistics for mangrove cover in different countries, but nevertheless there is broad consensus that over one quarter of the planet's original total mangrove cover has now gone. Although annual global rates of loss declined from just over 1.0% in the 1980s to 0.6% between 2000 and 2005, this is nevertheless still 3-5 times higher than the average rate of loss for all forests [3]. Many of the Asian countries lost over 20.0% of their mangrove cover within this period. The globally determining factor of mangrove loss is affected by the conversion of mangrove areas into shrimp farms [1]. Because of the conversion of mangrove forests to agricultural and aquaculture usage, the dramatic decline of mangrove forests in Irrawaddy Delta, South Myanmar during the past 30 years has been noticed and caused environment impacts, including habitat loss, reduction of biodiversity, and the increase of coastal erosion [4].

In recent years, remotely sensed data has been widely used to monitor and detect mangrove populations in tropic and subtropical regions. The availability of earth observation satellite data (such as Landsat) for three past decades is useful for detecting changes for mangrove forest. In addition to understand the mangrove change in the past, several prediction methods including statistical estimation [4] and spatial explicit models, such as Cellular Automata-Markov models [2] have been applied to analyze changes of land cover and to project future mangrove population scenarios. In this study, Probabilistic Landscape Simulation (ProLAMS), is proposed and applied for predicting the future change of mangrove forests over the region. Different from other methods that mainly focuses on the decline trend estimation, ProLAMS considers both the increase pattern and decrease pattern at the same time, to reflect the heterogeneous change of mangrove forest dynamics. To conduct the monitoring and prediction of mangrove forest over the Irrawaddy region, this study firstly aims to investigate the changes of mangrove forests using Landsat imageries during the periods of 1989 to 2014. Second, with calibrating and validating the model, this study predicts the future distribution of mangrove forests in 2030.

2. Study Area

The Irrawaddy Delta (Ayeyarwady Delta) locates in the Irrawaddy Division (Figure 1), the region with lowest elevation in Myanmar, from 290 km to the south at the mouth of the Ayeyarwady River. The delta region formed by the alluvium out from the limit of tidal influence at Myan Aung to the Bay of Bengal and Andaman Sea, and is densely populated. The cultivation of rice in rich alluvial soil as low as just 3 meters above sea level, although it also includes fishing communities in a vast area full of rivers and streams. Moreover, control of weeds is less active as local farmers make mats during the summer [3]. Mangroves are the major vegetation of the delta. On 2 May 2008, the delta suffered a major disaster, devastated by Cyclone Nargis, which reportedly killed over at least 77,000 people with over 55,900 missing, and left about 2.5 million homeless [5]. Destruction of mangroves and deforestation in the coastal region due to the Cyclone Nargis put it more at risk in future [4-5].

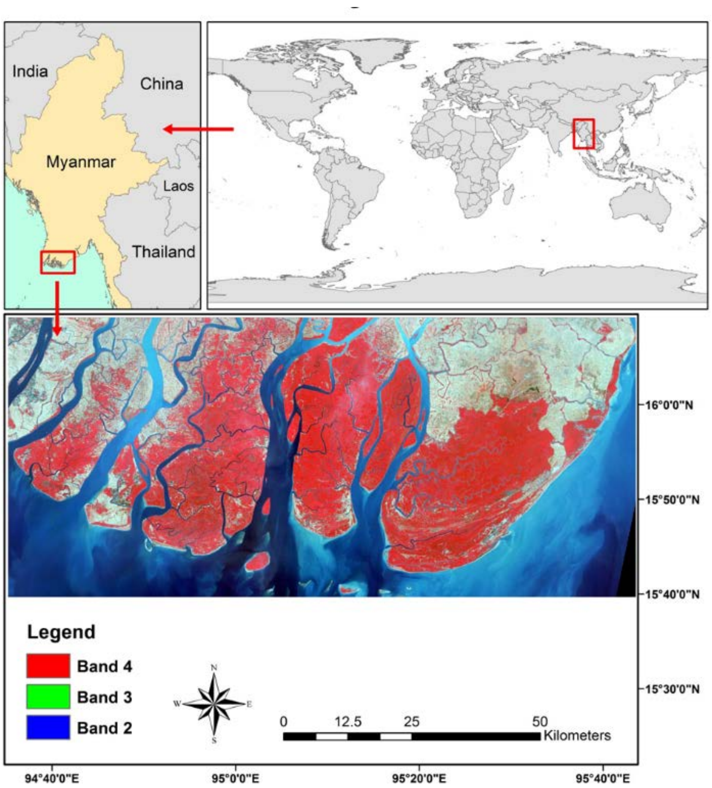

Figure 1: The location of study area, Irrawaddy Delta South Myanmar

3. Remote Sensing Data

This study collected Landsat images and 30 m ASTER GDEM2 for the study area in 1989, 2001 and 2014 (Figure 2). To map the mangrove forests, Object-Based Image Analysis (OBIA) with Support Vector Machine classifier (SVM). The overall accuracy and Kappa Coefficient are computed for assessing the mapping results. The changes of mangrove forests within different time periods can be therefore analyzed.

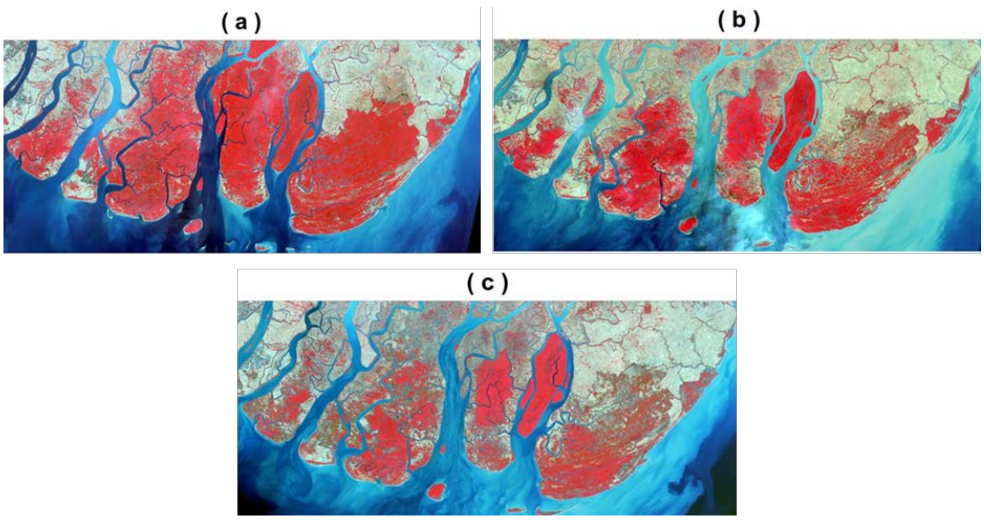

Figure 2: Landsat imagery of the study area: (a) 1989, (b) 2001 and (c) 2014

4. Probabilistic Landscape Simulation

The proposed ProLAMS (Probabilistic Landscape Simulation) is performed in a raster grid system, and has two components: (1) a statistic model for assessing the likelihood of the increase and decrease of mangrove forests, and (2) a Cellular Automata (CA) algorithm to simulate the dynamics of the change.

4.1. Logistic regression

The multinomial logistic regression is used as the statistical model for assessing the likelihood of mangrove change, and can be expressed as:

$$\text{logit}\ (y_j) = a_j + b_{1,j}x_1 + b_{2,j}x_2 + b_{i,j}x_i + \ldots + e_j \qquad (1)$$

where y_j is the dependent variable, representing the increase, decrease and no-change of mangrove forest within a certain period. Three logits were obtained to model the change of mangrove forest, and numerical numbers are used to represent the gird states, including the increase (j=1), the decrease (j=2) and no-change (j=3) of mangrove forest, respectively. a is a constant, b_i is the coefficient of independent variable x_i, and e is the random error term. Each logit (y_j) can be converted to the probability p_j by:

$$p_j = \frac{\text{logit}(y_j)}{1 + \text{logit}(y_j)} \qquad (2)$$

A logit model can be evaluated by the area under the receiver operating characteristic curve (AUC), which is based on the proportions of incidences correctly reported as positive (true positive) and incidences erroneously reported as positive (false positive). Using the AUC value, a predictive logit model can be classified as acceptable (AUC > 0.7), excellent (AUC > 0.8), or outstanding (AUC > 0.9).

4.2. Cellular Automata algorithm

The CA algorithm for simulating the probability change is assumed that the probability of mangrove change at a point can be influenced by not only the probability of the point itself but by probabilities of neighborhoods. In a raster grid system, the probability change within a time interval can be simply expressed by:

$$P_{0,t} = P_{0,t\text{-}1} + \Delta P_{0,t} \qquad (3)$$

where

$$\Delta P_{0,t} = \min\left\{\sum_{i=1}^{8} M_{i0,t}, 1\right\} \qquad (4)$$

P_0 is the probability of the focal cell 0 in a 3-by-3 grid, t the time, and M_{i0} the gain of probability from a neighboring cell i (i=1-8). The total gain of probability is the summation of M_{i0} which cannot exceed one. M_{i0} is a predefined function for delivering probabilities, which is determined by the probability gradient between focal and neighboring cells in the grid system:

$$M_{i0,t} = \begin{cases} \frac{k}{D} \cdot \left(\frac{P_{0,t-1}}{P_{i,t-1}} \right)^b, if P_{i,t-1} \geq P_{0,t-1} > 0 \\ 0, otherwise \end{cases} \quad (5)$$

where coefficient k and exponent b are parameters to be calibrated. D is the grid size. For analyzing the likelihood of mangrove change, useful variables are expected to be extracted from GIS data. Variables used in the study are: land cover types, including mangrove, farm land, waterbody and bare soil, nearest distance and direction to river networks and farm lands, slope gradient, elevation, aspect, image band of near infrared, image band of shortwave near infrared, normalized difference vegetation index (NDVI) and normalized difference water index (NDWI).

Variables respected to distances and directions were generated by using GIS. Mangrove maps of 1989 and 2001 were used to calibrate the model, and mangrove maps of 2001 and 2014 were used to validate the model. The AUC is calculated to assess the model performance. If acceptable or better AUC can be obtained with model validation, ProLAMS will be used to predict the mangrove distribution in 2030.

5. Results and Discussion

5.1. The change of mangrove forests from 1989 to 2014

The mapping accuracies of mangrove forest in 1989, 2001 and 2014 are 0.89 for overall accuracy and 0.78 for Kappa Coefficient averagely. Figure 3 shows the mapping results of the three years. The spatial pattern of mangrove changes between the two periods, 1989-2001 and 2001-2014 are shown in Figure 4. Table 1 lists the area change of mangrove forest from 1989 to 2014. Table 2 lists the mapping area in 1981, 2001 and 2014.

Table 1: Area change of mangrove forest in Irrawaddy Delta, 1989-2014

unit: km^2		1989-2001	2001-2014
Decrease	Area	572.54	403.82
	%	14.4 %	10.16 %
Increase	Area	327.78	195.2
	%	8.24 %	4.91 %

The heterogeneous distribution of increase and decrease of mangrove forests in space can be observed in Figure 3. Specifically, the decline of mangrove population in 1989-2001 is much server than 2001-2014, although some regeneration of mangrove can be found in the region. Overall, the total decline since 1989 has reached 26.7% of the total area.

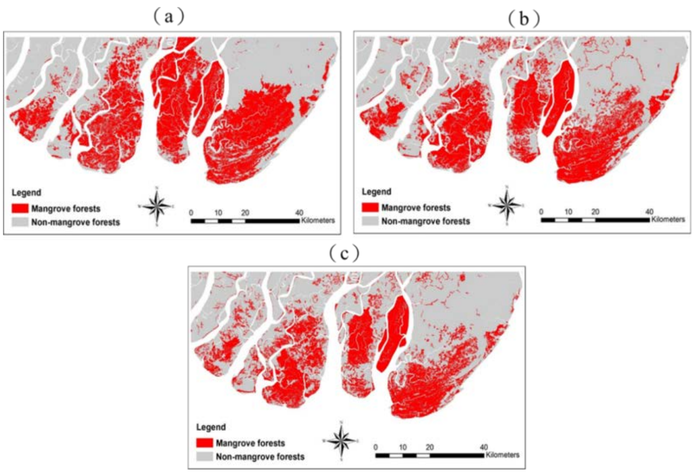

Figure 3: The mapping results of mangrove forest in (a) 1989, (b) 2001 and (c) 2014.

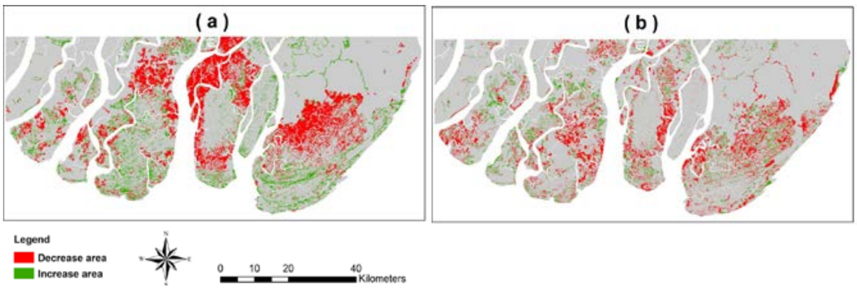

Figure 4: The spatial pattern of mangrove changes between (a) 1989-2001 and (b) 2001-2014.

5.2. The prediction of mangrove forests

To calibrate ProLAMS, mangrove map of 1989 was used as the initial condition to simulate the mangrove distribution in 2001, and mangrove map of 2001 was then used to compare with the simulation results, obtaining the AUC of 0.81. For model validation, mangrove map of 2014 was used to compare with simulation result of 2014 and obtained AUC of 0.79. Table 2 lists the estimated mangrove area through image classification and model prediction. The predicted mangrove areas are very close to image classification. Figure 5 displays the future prediction of mangrove forest in 2030, by ProLAMS. The predicted area is 1060.5 km^2 which is about 16.8% decline comparing with year of 2014.

Table 2: Mangrove area estimation and prediction

unit: km^2		Image classification	Model prediction
Year	1989	1707.5 (43.0%)	--
	2001	1462.7 (36.8%)	1499.4 (37.7%)
	2014	1254.1 (31.5%)	1274.3 (32.1%)
	2030	--	1060.5 (26.7%)

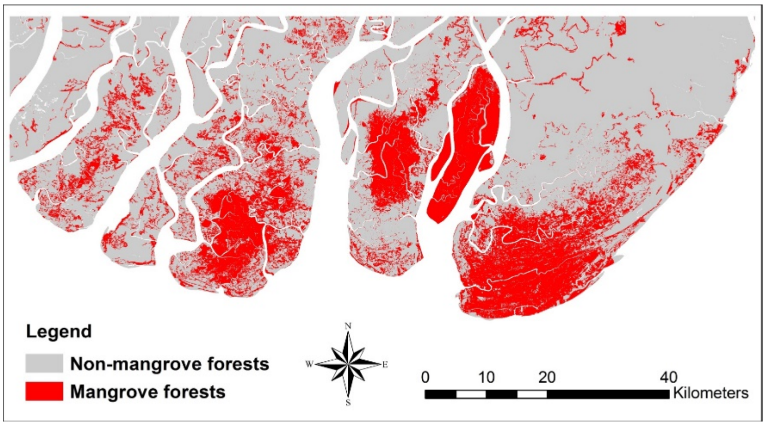

Figure 5: The predicted mangrove forest in Irrawaddy Delta, 2030

6. Limitations and Recommendations

To monitor the changes of mangrove forests, this study applied Landsat images with spatial resolution of 30 m, and this may case the uncertainty in mangrove mapping accuracies. The application of other higher resolution remote sensing data, including aerial photography, may improve the image classification task. In addition, the application of ProLAMS can be performed better if knowledge for locality can be incorporated. For example, interviews with local people may assist realizing the driving factors of mangrove decline in more detail.

7. Conclusion

This study investigates the changes of mangrove forests over the region of Irrawaddy Delta, using Landsat images of 1989, 2001 and 2014. A proposed mangrove prediction model, Probabilistic Landscape Simulation (ProLAMS), is applied for predicting the distribution of mangrove forests over the region in 2030. First, according to the change detection with mapped mangrove forests, both increase and decrease patterns can be found in the region, but area of decrease is more significant than increase, showing about 26.7% decline of mangrove area in the period of 1989-2014. Second, based on the model prediction, 16.8% decline of mangrove area from 2014 to 2030 is predicted. In sum, this study suggests that satellite imagery and land cover model can be integrated to provide future scenarios of mangrove forest for Irrawaddy delta, South Myanmar. We expect this approach can be useful and applicable for other regions to assist ecosystem conservation activity.

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